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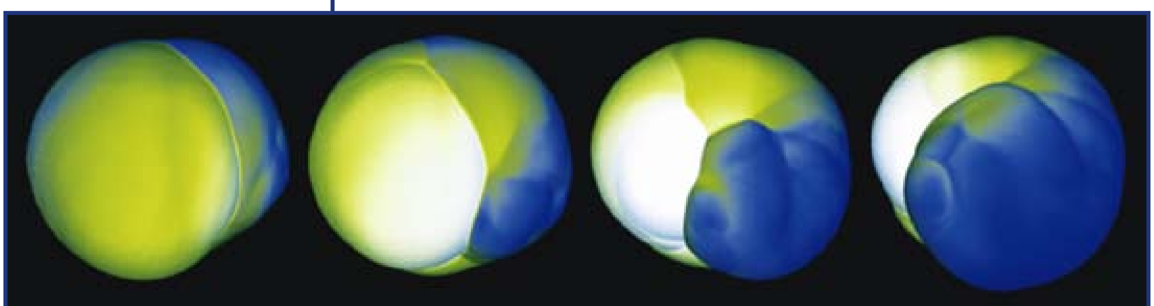
ORNL Team Discovers New Way to Spin Up Pulsars

In 1967, a Cambridge University graduate student poring over data from a newly constructed radio telescope noticed something new and odd—a radio signal blinking regularly from a far corner of the sky.

The signal came from a pulsar, the spinning remnant of a core-collapse supernova. A pulsar appears to blink because radiation shoots out of its magnetic poles, which, as with the earth, can be tilted a little from its axis of spin. As a result, the pulsar behaves like a stellar lighthouse, pointing at an observer once with each rotation.



This visualization shows the propagation of a stationary accretion shock instability wave in a core-collapse supernova. The leading edge of a spiral flow near the surface of the supernova shock is marked by the blue area in the figure. It is accompanied by a second flow spinning in the opposite direction underneath. This second spinning flow is responsible for imparting the pulsar spin, according to three-dimensional simulations performed at Oak Ridge National Laboratory. Image courtesy of John Blondin

Nearly four decades later, a team of scientists using Oak Ridge National Laboratory (ORNL) supercomputers has discovered the first plausible explanation for a pulsar's spin that fits the observations made by astronomers. Their surprising results show that the spin of a pulsar is not just a continuation from the massive star that preceded it; in fact, the pulsar spin can be in the opposite direction.

Anthony Mezzacappa of ORNL and John Blondin of North Carolina State University explain their results in the January 4, 2007, issue of the journal Nature. According to three-dimensional simulations they performed at the National Center for Computational Sciences (NCCS), the spin of a pulsar is determined not by the spin of the original star, but by the shock wave created when the star's massive iron core collapses.

That shock wave is inherently unstable, a discovery the team made in 2002. The instability creates two rotating flows—one in one direction directly below the shock wave and another, inner flow, that travels in the opposite direction and spins up the core.

The discovery comes at an opportune time, because astronomers did not have a workable explanation for how the pulsar gets its spin. The assumption to this point has been that the spin of the leftover collapsed core comes from the spin of the original star. The problem with that approach is that it would explain only the fastest observed pulsars. The ORNL team, on the other hand, predicts spin periods that are in the observed range between 15 and 300 milliseconds.

The discovery is an outgrowth of the team's use of three-dimensional simulations and the advances in high-performance computing that made the simulations possible. The simulations performed for the Nature paper used the Cray X1E system at ORNL, known as Phoenix. Later simulations done by the team made use of the center's Cray XT3 system, known as Jaguar.

Mezzacappa stressed that the team is looking forward to further advances in high-performance computing that will be coming to ORNL. For example, the team's simulations have not incorporated the influence of nearly massless, radiation-like particles known as neutrinos and the star's magnetic field.

The real prize, though, for his and other teams is a complete explanation of how the collapse of a star's core leads to the explosion that ejects most of its layers. So far, that explanation has proved elusive.

"That is one of the most important unsolved problems in astrophysics," Mezzacappa said. "Core-collapse supernovae are the dominant source of elements in the universe, and the mechanism has everything to do with that."

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